

# **Bibliometric analysis of quality function deployment with fuzzy systems**

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## **ABSTRACT**

Research on quality function deployment (QFD) with fuzzy systems has increased since the 2000s. The growing number of QFD applications with fuzzy systems indicates worldwide attention on this field of research. Then, two research questions arise: Are there some trends? And, are there some research gaps? This paper presents bibliometric analysis to answer those questions, performed on data from Scopus database, in a total output of 598 documents. Only articles and reviews were searched. China is the leading country in publication and international collaboration (207 published documents, more than a third of total). The main finding of analysis is the trend of QFD integration with fuzzy and multi-criteria decision-making (MCDM) methods. This could be observed with different applications as new product development, quality management, service quality, and supply chain management, to name a few.

**Keywords:** Bibliometrics, fuzzy systems, quality function deployment, Scopus.

## INTRODUCTION

Quality function deployment (QFD) is a method to translate, in an efficient way, needs of customers into development of new products or improvements in current ones (Kwong and Bai, 2002). However, a few proposals have been presented to enhance the performance of the original QFD method (Carnevalli and Miguel, 2008; Sivasamy et al, 2016).

Fuzzy systems have been successfully applied to deal with imperfect, vague, and imprecise information, often found in decision problems, including the QFD method (Rodriguez et al, 2016). In one of the first applications, a method of a robust design was developed for Kraslawski et al (1993). Fuzzy systems were applied in the “House of Quality”: The main idea was to minimize the variability of product quality under fuzzy technological and economic constraints. Also, in early 1990’s, fuzzy linear regressions equations were applied in QFD to estimate relationships among variables with limited and uncertain data (Moskowitz and Kim, 1993).

Fuzzy systems have also been applied to determine weights for customers’ requirements (Akao, 2004; Kwong and Bai, 2003; Li et al, 2014). These applications include multi-criteria decision making (MCDM) methods, as the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Afterwards, developments in fuzzy systems, including intuitionistic fuzzy sets were integrated to MCDM for QFD (Jian et al, 2016; Onar et al, 2016; Osiro et al, 2018; Wang et al, 2017; Wu et al, 2017).

The growing number of QFD applications with fuzzy systems indicates worldwide attention on this field of research. Then, two questions arise: Are there some trends? And, are there some research gaps? This paper presents a bibliometric analysis which aims to answer those questions. Therefore, this is a literature review paper. Methodologically, it was performed a bibliometric study (Yataganbaba and Kurtbas, 2016; Zyoud and Fuchs-Hanusch, 2017). Section 2 presents a literature review on QFD and fuzzy systems. Section 3 presents methodological subjects. Section 4 points out bibliometric results. Section 5 presents contents analysis, and Section 6 the Conclusions.

## LITERATURE REVIEW

### *Quality Function Deployment*

QFD was developed by Dr. Yoji Akao and Dr. Shigeru Mizuno (Akao, 2004). Then, many researchers and professionals have proposed adaptations and improvements in the original QFD. Although QFD has been originally developed for product development planning, its applications have extended to

different processes such as costs analysis, managerial decision making, process planning, engineering, and teamwork, to name a few (Chan and Wu, 2002).

A complete QFD application consists of several relationship matrices. House of Quality (HOQ) is the first matrix, which translates customers' needs into technical characteristics of the product (Kahraman et al, 2006). Customers' requirements (CR) are obtained through surveys or direct questions to the customers. To develop a new product, CR must be translated into engineering characteristics (EC) (Chen et al, 2014).

HOQ has been used to determine the relationship between customers' needs, or CR, and quality characteristics or EC (Govers, 2001). Moreover, there are benchmark data (marketing and technical) which individually represent the competitive analysis upon customers and technology (Chen et al, 2014).

In the traditional QFD, the relationship between CR and EC is determined by a project team using linguistic expressions, such as: "very low", "low", "medium", "high" and "very high", with values that range from 1 to 5 being assigned to them (Chen et al, 2014). In addition, some QFD applications combine the method with MCDM techniques such as AHP or TOPSIS and fuzzy systems, to deal with the subjectivity and uncertainty of quality matrices analyses (Carnevalli and Miguel, 2008; Chan and Wu, 2002).

### ***Fuzzy Systems***

Fuzzy Sets Theory (FST) was introduced to deal with the uncertainty due to imprecision and vagueness (Tong and Bonissone, 1980). A fuzzy set  $X$  is characterized by a membership function  $\mu$ , which assigns to each element  $x$  in the set a grade of membership ranging from zero to one (Zadeh, 1965). That is, each element in a fuzzy set is associated with a value indicating to what degree the element is a member of the set (Bevilacqua et al, 2006). A major contribution of FST is the capability of representing vague data (Buyukozkan et al, 2004).

Despite that, when handling vague and imprecise information whereby two or more sources of vagueness arise concurrently, the modeling tools of ordinary fuzzy sets have limitations. Hence, different generalizations and extensions of fuzzy sets have been introduced (Rodriguez et al, 2012).

Figure 1 presents an evolution of FST (Kahraman et al, 2016): from original type-1 fuzzy sets (Yataganbaba and Kurtbas, 2016), through type-n fuzzy sets (Zadeh, 1975) and interval-valued fuzzy sets (Zadeh, 1975; Grattan-Guinness, 1976), following by intuitionistic fuzzy sets (Atanassov, 1986), fuzzy multisets (Yager, 1986), nonstationary fuzzy sets (Garibaldi and Ozen, 2007) and, finally, hesitant fuzzy sets (Torra, 2010).

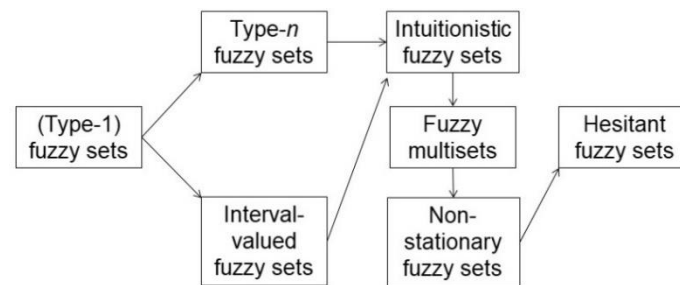


Figure 2 – Evolution of fuzzy sets theory (Kahraman and Onar, 2016).

Type-2 fuzzy sets and type-n fuzzy sets incorporate uncertainty about the membership function in their definition (Rodriguez et al, 2012). Membership function of type-2 fuzzy sets ranges over a type-1 fuzzy set. Generalizing, membership function of a type-n fuzzy set ( $n = 2, 3, 4...$ ) ranges over a type-n-1 fuzzy set (Zadeh, 1975; Melin et al, 2013).

Nonstationary fuzzy sets introduce into the membership functions a connection that expresses a slight variation on them (Rodriguez et al, 2012).

Intuitionistic fuzzy sets extend fuzzy sets by an additional degree: the degree of uncertainty (Rodriguez et al, 2012). Intuitionistic fuzzy sets also incorporate a degree of hesitation, defined as 1 minus the sum of membership  $\mu$  and non-membership  $\nu$  degrees (Kahraman et al, 2018).

Fuzzy multisets based on multisets allow repeated elements in the set (Rodriguez et al, 2012). They are based on the concept of bags (Yager, 1986). A bag is a set with repeated elements.

Hesitant fuzzy set (HFS) is the most recently introduced extension of fuzzy sets. An HFS allows the modeling of uncertainty originated by the hesitation arisen in the assignment of membership degrees of the elements to a fuzzy set (Torra, 2010).

## RESEARCH METODOLOGY

Usually, bibliometric analyses are performed in one of four databases: Google Scholar, PubMed, Scopus, or Web of Science (Falagas et al, 2008). This paper presents a Scopus-based bibliometric analysis. Scopus was preferred because of the greater number of journals it contains (Zyoud and Fuchs-Hanusch, 2017). Scopus provides flexible review for several fields of science (Kulkarni et al, 2009). It allows the collected data to be analyzed without the need to separate the different sections (Yataganbaba and Kurtbas, 2016).

Scopus database was first searched for QFD with fuzzy systems in general. For this, the search bars of *abstract*, *keywords* and *title* on Scopus database were first filled with “fuzzy”, “house of quality”, “QFD”, and “quality function deployment”. Both Boolean operators “and” and “or” were searched. The query was it as follows: TITLE-ABS-KEY(QFD) OR TITLE-ABS-KEY (“quality function deployment”) OR TITLE-ABS-KEY (“house of quality”) AND TITLE-ABS-KEY (fuzzy) AND PUBYEAR < 2020. Only articles and reviews were searched.

Besides authorship, details such as citation, country, document type, impact factor (IF), institution, journal name and prevalent interest area were considered.

Citations were counted considering h-index. This indicator includes measures of quantity (amount of publications) and quality (citation rates) (Egghe., 2006). On Scopus, journals can be sorted with three indicators: Cite Score, SCImago Journal Rank (SJR) and Source Normalized Impact per Paper (SNIP). Cite Score measures average citations received per document published in the journal. SJR measures weighted citations received by the journal. Citation weighting depends on subject field and prestige of the citing journal. SNIP measures actual citations received in comparison to the citations expected for the journal’s subject field.

For each considered journal, IF was extracted from the Journal Citation Reports (Clarivate Analytics, 2018) and word frequencies were used in content analysis (Wang et al, 2017). Keywords have a great potential to reflect the focus of research. According to Tan et al (2014) the core words indicate the core literature within a specific field of research.

Co-occurrence analysis of keywords was performed with VOSviewer. This software builds maps of networks and uses “visualization of similarities” techniques of clustering, which are widely used in bibliometric analysis (Van Eck and Waltman, 2010).

After bibliometric analysis about QFD on the fuzzy environment, new searches were performed inserting, separately, those new expressions: “hesitant”, “intuitionistic”, “nonstationary”, “type-2” and “multiset”. The objective in the second search was to verify if there was any publication about QFD in other extensions of fuzzy environment

For the QFD method on Hesitant fuzzy environment, for example, the query was as follows: TITLE-ABS-KEY(QFD) OR TITLE-ABS-KEY ("quality function deployment") OR TITLE-ABS-KEY ("house of quality") AND TITLE-ABS-KEY (fuzzy) AND TITLE-ABS-KEY (Hesitant) AND PUBYEAR < 2020. Only articles and reviews were searched.

## RESULTS

### *Ranks of Publications*

The research performed, as described in Section 3, resulted in 598 documents: 588 articles and 11 reviews. That is, the overwhelming majority of publication is from articles, or else, original findings. Then, there is a lack on reviews in the QFD and fuzzy systems literature. Presenting a literature review, this paper contributes to the diversification of the literature of the researched field. The yearly average of publications is 22.

A gradual increase is observed, with a steep rise and breakthrough, in 2007. More than 79% of documents were published after 2007 (Figure 2). The years of 2009 and 2019 were outliers with more than 50 documents published. From 2010 to 2018, documents per year average 39. China is the leading country in published documents on QFD and fuzzy systems (Table 1). The 207 documents published by China are more than a third of the total. This result is even more impressive considering that Scopus counts China, Hong Kong and Taiwan, independently.

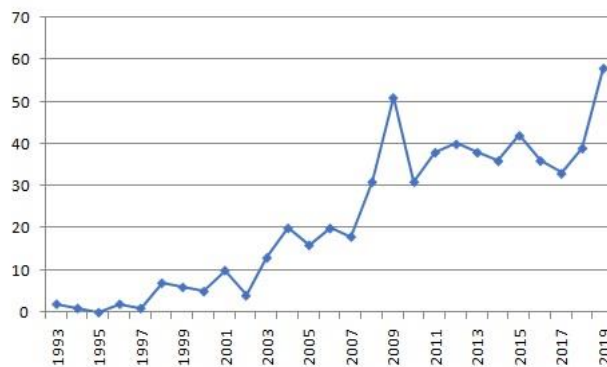


Figure 2 – Publication by year

Table 1 - Publications by country

| Rank | Country             | Documents | h-index | Citations |
|------|---------------------|-----------|---------|-----------|
| 1    | China (CHN)         | 207       | 26      | 3,104     |
| 2    | Taiwan (TWN)        | 108       | 30      | 2,738     |
| 3    | Turkey (TUR)        | 63        | 26      | 2,452     |
| 4    | Iran (URN)          | 53        | 15      | 674       |
| 5    | India (IND)         | 51        | 15      | 571       |
| 6    | United States (USA) | 34        | 17      | 1,442     |
| 7    | Hong Kong (HK)      | 33        | 22      | 2,622     |
| 8    | United Kingdom (UK) | 22        | 14      | 1,038     |
| 9    | Singapore (SGP)     | 19        | 14      | 933       |
| 10   | Canada (CAN)        | 12        | 7       | 313       |

The average h-index for the top ten countries is 18 and the average of citations is greater than 2,500 citations per document. The 598 resulting documents received more than 15,000 citations. China keeps leading the rank considering the international collaboration (Table 2), besides of the moves in lower positions. Researches from Hong Kong and from the United States result from collaborations with more countries. However, China is the most collaborative country in the top ten.

Table 2 - Publications by international collaboration

| Rank | Country | Documents | Collab. Countries | Top country |
|------|---------|-----------|-------------------|-------------|
| 1    | CHN     | 51        | 12                | HK          |
| 2    | HK      | 31        | 8                 | CHN         |
| 3    | USA     | 24        | 10                | TUR         |
| 4    | UK      | 21        | 13                | CHN         |
| 5    | IRN     | 17        | 9                 | USA         |
| 6    | TWN     | 16        | 6                 | CHN         |
| 7    | TUR     | 15        | 7                 | USA         |
| 8    | SGP     | 11        | 6                 | China       |
| 9    | CAN     | 7         | 4                 | China       |
| 10   | IND     | 2         | 2                 | Ethiopia    |

The institution with more documents published by first authors is *Galatasaray Universitesi*, from Turkey (Table 3), with 28 documents. The publication is worldwide spread in a hundred institutions. China has eleven institutions ranked in the top 20. This is a result of the active participation of China in this field of research. The most prolific author is Jiafu Tang, from Dongbei University of Finance and Economics, China. Dr. Tang published 26 documents (Table 4). Publishing 30 documents, Expert Systems with Applications (ESWA) is the leading journal (Table 5). ESWA is the second journal on Cite Score and IF (Table 6), leaded by Journal of Cleaner Production (JCP). On SJR, European Journal of Operational Research ranks first, followed by JCP, International Journal of Production Research, Journal of Intelligent Manufacturing and Computers and Industrial Engineering. ESWA leads on SNIP.

Engineering and Computer Science are the leading interest areas (Table 7). ESWA is the top journal in both areas. China is the top country in almost all areas, except Business, Management and Accounting, and Social Sciences. Three top authors, Kahraman, Ertay and Buyukozkan, co-authored the most cited document (Kahraman et al, 2006), which is cited 454 times (Table 8).

Table 3 - Publications by Institution

| Rank | Institution  | Country | Documents |
|------|--|---------|-----------|
| 1    | Galatasaray Universitesi   | TUR     | 28        |
|      | Northeastern University, China                                       | CHN     | 28        |
| 3    | Shanghai University  | CHN     | 18        |
| 4    | Hong Kong Polytechnic University                                     | CHN     | 17        |
|      | City University of Hong Kong   | CHN     | 17        |
| 6    | National Institute of Technology, Tiruchirappalli                    | IND     | 16        |
|      | Southwest Jiaotong University  | CHN     | 16        |
|      | National Cheng Kung University                                       | TWN     | 16        |
| 9    | National Chin-Yi University of Technology Taiwan                     | TWN     | 13        |
| 10   | National Taiwan Ocean University                                     | TWN     | 12        |
|      | The International Joint Research Laboratory of Integrated Automation | CHN     | 12        |
| 12   | Zhejiang University  | CHN     | 11        |
|      | Istanbul Teknik Universitesi   | TUR     | 11        |
|      | Kun Shan University  | TWN     | 11        |
| 15   | Nanyang Technological University                                     | SGP     | 10        |
|      | Shanghai Jiao Tong University  | CHN     | 10        |
|      | Tsinghua University  | CHN     | 10        |
| 18   | Chang Jung Christian University                                      | TWN     | 9         |
| 19   | University of Shanghai for Science and Technology                    | CHN     | 8         |
|      | Beihang University   | CHN     | 8         |

Table 4 - Publications by First Author

| Rank | First Author  | Country | Documents |
|------|---------------|---------|-----------|
| 1    | J. Tang       | CHN     | 26        |
| 2    | Y. Chen       | CHN     | 17        |
| 3    | Y. L. Li      | CHN     | 16        |
| 4    | G. Buyukozkan | TUR     | 12        |
|      | R.Y.K. Fung   | HK      | 12        |
|      | E.E. Karsak   | TUR     | 12        |
| 7    | C. K. Kwong   | CHN     | 11        |
|      | Y. Pu         | CHN     | 11        |
| 9    | L. H. Chen    | TWN     | 10        |
|      | W. C. Ko      | TWN     | 10        |
|      | S. Vinodh     | IND     | 10        |
| 12   | J. F. Ding    | TWN     | 8         |
|      | C. Kahraman   | TUR     | 8         |
|      | G. S. Liang   | TWN     | 8         |
| 15   | X. Geng       | CHN     | 7         |
|      | L. P. Khoo    | SGP     | 7         |
|      | L. Z. Lin     | TWN     | 7         |
| 18   | X. Chu        | CHN     | 5         |
|      | T. Ertay      | TUR     | 5         |
|      | A. Liu        | CHN     | 5         |



Table 5 - Publications by Journal

| Rank | Journal  | Documents |
|------|--|-----------|
| 1    | Expert Systems with Applications (ESWA)  | 30        |
| 2    | International Journal of Production Research (IJPR)                              | 29        |
| 3    | Jisuanji Jicheng Zhizao Xitong (Computer Integrated Manufacturing Systems, CIMS) | 27        |
| 4    | Computers and Industrial Engineering (CAIE)                                      | 21        |
| 5    | Total Quality Management and Business Excellence (TQMBE)                         | 13        |
| 6    | International Journal of Advanced Manufacturing Technology (IJAMT)               | 12        |
| 7    | European Journal of Operational Research (EJOR)                                  | 11        |
|      | Journal of Intelligent Manufacturing (JIM)                                       | 11        |
| 9    | Applied Soft Computing Journal (ASCJ)  | 10        |
|      | Journal of Cleaner Production (JCP)  | 10        |
| 11   | Jixie Gongcheng Xuebao (Chinese Journal Of Mechanical Engineering, CJME)         | 9         |
|      | Quality and Quantity (QQ)  | 9         |
|      | Zhongguo Jixie Gongcheng (China Mechanical Engineering, CME)                     | 9         |
| 14   | Journal of Intelligent and Fuzzy Systems (JIFS)                                  | 8         |
| 15   | Sustainability Switzerland (SS)  | 7         |
| 16   | Computers in Industry (CII)  | 6         |
|      | International Journal of Logistics Systems and Management (IJLSM)                | 6         |
|      | International Journal of Productivity and Quality Management (IJPQM)             | 6         |
| 19   | Applied Mathematical Modelling (AMM)   | 5         |
|      | Concurrent Engineering Research and Applications (CERA)                          | 5         |

Table 6 - Citations by Journal

| Rank | Journal | Cite Score | SJR (2018) | SNIP (2018) | IF   |
|------|---------|------------|------------|-------------|------|
| 1    | ESWA    | 6.36       | 1.190      | 2.696       | 5.71 |
| 2    | IJPR    | 4.34       | 1.585      | 1.720       | 3.93 |
| 3    | CIMS    | 0.84       | 0.299      | 0.591       | -    |
| 4    | CAIE    | 4.68       | 1.334      | 1.755       | 3.30 |
| 5    | TQMBE   | 2.44       | 0.776      | 1.425       | -    |
| 6    | IJAMT   | 3.04       | 0.987      | 1.596       | 2.69 |
| 7    | EJOR    | 4.98       | 2.205      | 2.455       | 3.03 |
| 8    | JIM     | 4.20       | 1.389      | 1.921       | 2.32 |
| 9    | ASCJ    | 6.27       | 1.216      | 2.369       | 2.21 |
| 10   | JCP     | 7.32       | 1.620      | 2.308       | 2.35 |
| 11   | CJME    | 1.10       | 0.435      | 0.927       | 1.00 |
| 12   | QQ      | 1.40       | 0.421      | 0.886       | -    |
| 13   | CME     | 0.38       | 0.217      | 0.428       | 1.37 |
| 14   | JIFS    | 1.96       | 0.412      | 0.818       | -    |
| 15   | SS      | 3.01       | 0.549      | 1.169       | -    |
| 16   | CII     | 6.05       | 1.242      | 2.395       | -    |
| 17   | IJLSM   | 1.31       | 0.330      | 0.758       | -    |
| 18   | IJPQM   | 1.33       | 0.345      | 0.736       | -    |
| 19   | AMM     | 3.36       | 0.873      | 1.495       | -    |
| 20   | CERA    | 1.79       | 0.549      | 1.225       | -    |

Table 7 - Publications by Interest Area

| Rank | Area                                | Documents   | Journal             | Country |
|------|-------------------------------------|-------------|---------------------|---------|
| 1    | Engineering                         | 367 (61.37) | ESWA                | CHN     |
| 2    | Computer Science                    | 267 (44.65) | ESWA                | CHN     |
| 3    | Business, Management and Accounting | 141 (23.58) | IJPR                | TWN     |
| 4    |                                     | 110 (18.39) | IJPR                | CHN     |
| 5    | Mathematics                         | 109 (18.23) | EJOR                | CHN     |
| 6    | Social Sciences                     | 37 (6.19)   | QQ                  | TWN     |
| 7    | Environmental Science               | 32 (5.35)   | JCP                 | CHN     |
| 8    | Energy                              | 24 (4.01)   | JCP                 | CHN     |
| 9    | Multidisciplinary                   | 14 (2.34)   | Tongji Daxue Xuebao | CHN     |
| 10   | Materials Science                   | 12 (2.01)   | JTE                 | CHN     |

Table 8 - Most Cited Documents

| Rank | Document                 | Citations | Rank | Document                     | Citations |
|------|--------------------------|-----------|------|------------------------------|-----------|
| 1    | Kahraman et al (2006)    | 454       | 11   | Bottani & Rizzi (2006)       | 158       |
| 2    | Kwong & Bai (2002)       | 301       | 12   | Fung et al. (1998)           | 156       |
| 3    | Kwong & Bai (2003)       | 299       | 13   | Vanegas & Labib (2001)       | 149       |
| 4    | Chan & Wu (2005)         | 274       | 14   | Bayou & de Korvin (2008)     | 146       |
| 5    | Bevilacqua et al. (2006) | 266       | 15   | Chen & Weng (2006)           | 145       |
| 6    | Kim et al. (2000)        | 220       | 16   | Tang et al. (2002)           | 144       |
| 7    | Chan et al. (1999)       | 217       | 17   | Bouchereau & Rowlands (2000) | 142       |
| 8    | Khoo & Hot (1996)        | 198       | 18   | Büyüközkan et al, (2004)     | 138       |
| 9    | Temponi et al. (1999)    | 170       | 19   | Chen et al. (2006)           | 135       |
| 10   | Wang (1999)              | 169       | 20   | Karsak (2004)                | 125       |

### Contents Analysis

The analysis of the word frequency in published research has been a widely used tool to examine the content analysis of research (Wang et al 2017). The author keywords have a great potential to reflect the focus of research because the core words indicate the core literature within a specific field of research. It also helps identify the central topics and hot spots that will continue to be vital in the examined field of research, besides helping suggest new directions for science in the future (Tan et al, 2014; Zyoud and Fuchs-Hanusch, 2017).

Analysis of the co-occurrence of keywords of published research to examine the hot research areas was conducted by VOSviewer software. This software builds visualization maps relied on data of networks and uses the “visualization of similarities” mapping and techniques of clustering, which are

widely used in the analysis of bibliometric networks (Van Eck and Waltman, 2010; Zyoud and Fuchs-Hanusch, 2017).

In the resulting 598 documents there were a total of 1,432 keywords. There were 69 keywords that appeared at least in five different documents. Figure 3 presents a network map obtained with Software VOSviewer. Figure 4 displays the density visualization map-item density in association with published research that utilized QFD method on fuzzy environment. The central keywords are in the darkest areas (from red to blue)

For the same concept, different authors used different keywords. As a limitation of VOSviewer, in this case, keywords were counted apart. That is, "Quality function deployment", "QFD" and "Quality function deployment (QFD)" were counted as different keywords. Given this, eight keywords clusters were identified (Table 9).

The keyword analysis shows that there is a trend to apply hybrid methods, combining fuzzy systems, MCDM and QFD. The most used MCDM methods are AHP, ANP (Analytic network process), TOPSIS and GRA (Grey Relational Analysis). In addition, some authors use more than one MCDM method simultaneously. Advances in fuzzy systems application in MCDM are not independent of fuzzy systems application in QFD.



### Table 9 - Clusters of keywords

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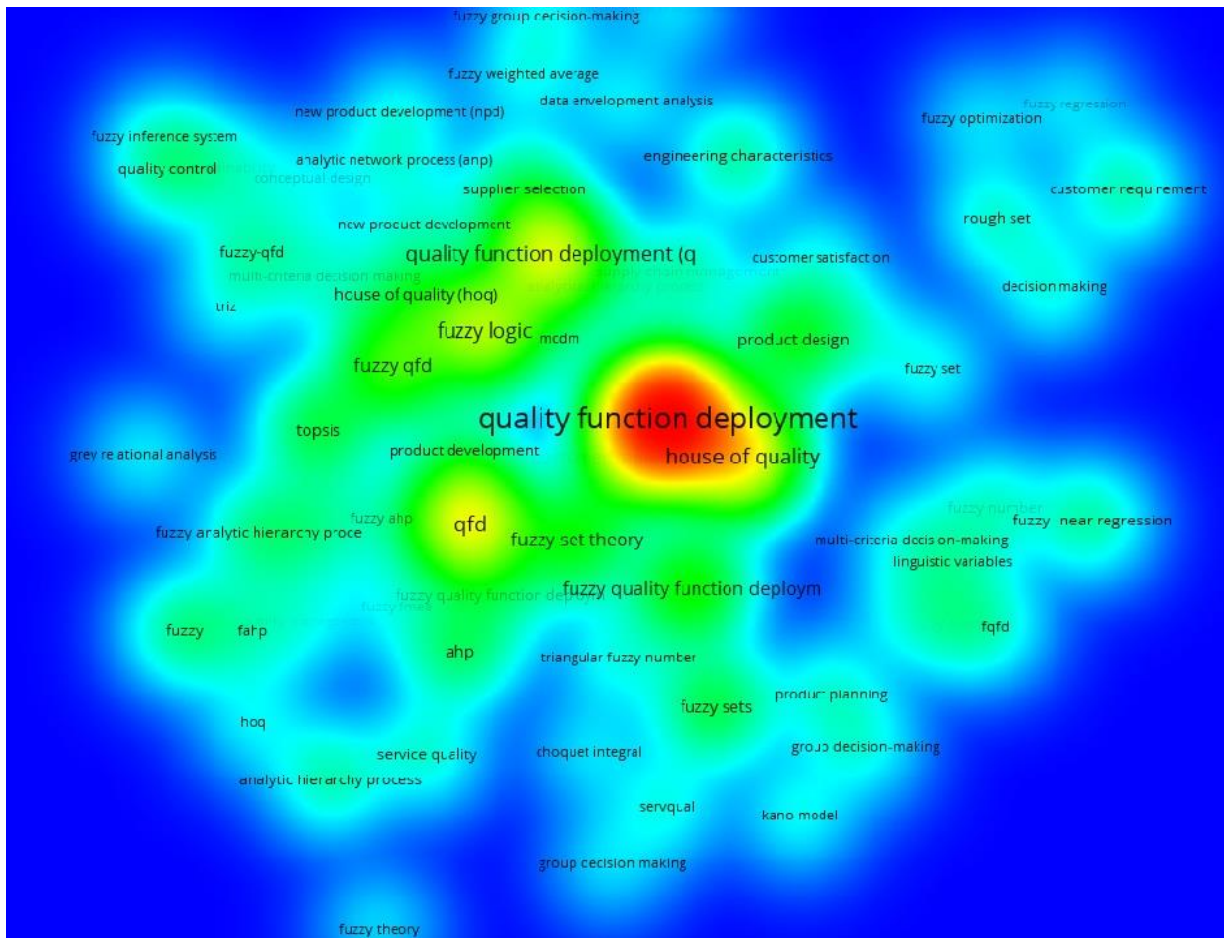


Figure 4 – Map-item density of keywords

Therefore, this is the hot topic of research on QFD and fuzzy systems: their integration with MCDM. Different applications were observed, including: "multi-criteria decision making", "Quality management", "service quality", "quality control", "supplier selection", "supply chain management", "sustainability", "Customer satisfaction", "product design", "conceptual design", "new product development", "product planning", and "Collaborative product development", to name a few. Moreover, "Choquet integral" was used in "group decision making" problems, such as determining a correlation among customer requirements (Yu et al, 2018).

Other topics of investigation include the Kano Model, FMEA and SERVQUAL, and "fuzzy goal programming", "fuzzy linear regression", "fuzzy optimization", "fuzzy regression" and DEA (Data Envelopment Analysis) among others. The use of different types of fuzzy systems is a promising topic of research.

Map-item density also shows that there is a trend to use MCDM methods, such as AHP and TOPSIS, for example, with QFD method on fuzzy environment, forming new hybrid MCDM methods for solving decision problems.



Different generalizations and extensions of fuzzy sets have been introduced in MCDM methods, such as in AHP and TOPSIS, for example, that had already been used with QFD method. Therefore, it is assumed that new hybrid MCDM methods will be created using QFD in their composition on other extension of fuzzy environment.

## **ACKNOWLEDGEMENTS**

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## **CONCLUSIONS**

This paper presents a bibliometric analysis on fuzzy systems applied to QFD. The first quantitative result is the growing number of publications observed since 2008. The second result is the leading position of China, both in publication and international collaborations.

A qualitative result from the research is the widely spread publications in terms of authorship, interest area and journals. However, Computer Science and Engineering are the leading areas, with far more publications than other areas. Therefore, Expert Systems with Applications is the journal which published more documents on QFD with fuzzy systems. Two groups of researchers have outstanding publication productivity. A group led by Dr. Kahraman, in Turkey, and another led by Dr. Y. Chen, in China.

A strong relationship between MCDM and QFD with fuzzy systems could be identified as the highest studied topic. Innovations in fuzzy systems theory have also been applied to QFD, as the intuitionistic fuzzy systems and the hesitant fuzzy systems. However, no publication on type-2 fuzzy set, fuzzy multisets and nonstationary fuzzy sets were found despite having been successfully applied in multicriteria decision methods. A study on the advantage of applying these fuzzy extensions in the QFD method would be a research gap to be addressed by researchers.

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